NOAA-USGS Debris-Flow Warning System for Recently-Burned Areas in Southern California: Lessons Learned from 5 Years of Operation

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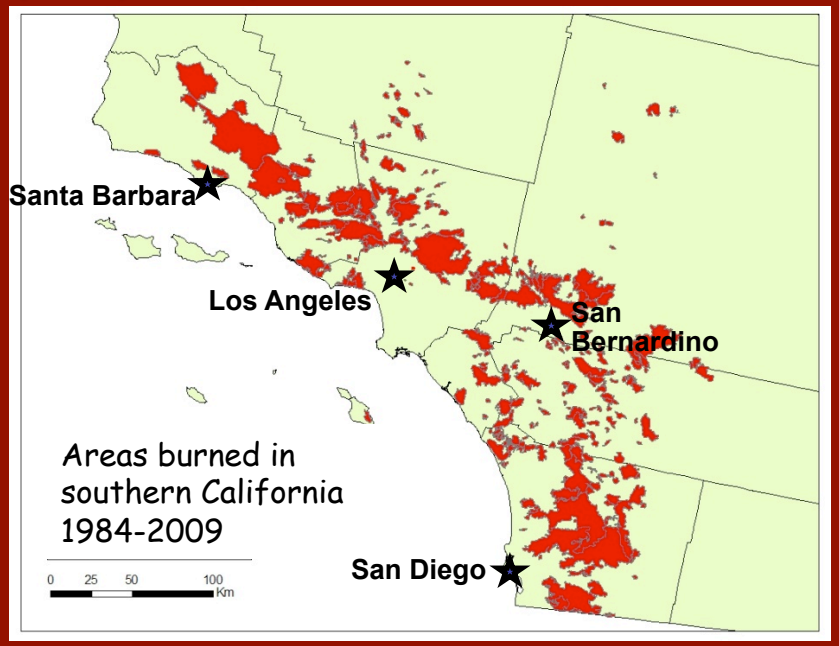
The Problem: Debris flows and floods following wildfires in southern California post significant hazards to life and property

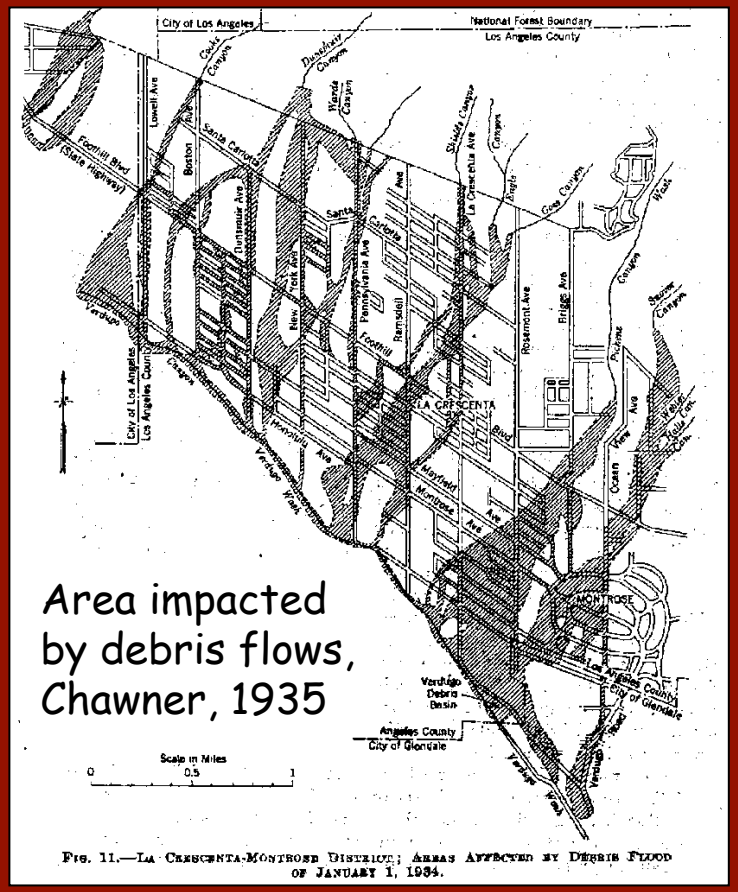


Extensive wildfires are a frequent occurrence in southern California

The Problem:

Post-fire debris flows from the San Gabriel Mountains, 1933-34

- 55 deaths
- 438 homes destroyed
- 660,000 m^3 of material



Area impacted by debris flows, Chawner, 1935

FIG. 11.—LA CRESCENTA-MONTROSE DISTRICT; AREAS AFFECTED BY DEBRIS FLOOD OF JANUARY 1, 1934.

Foothill Bl. near Castle Rd.

A nearly continuous record of post-fire debris flows:

2009 Station fire:

- 4 debris-flow producing storms
- No deaths (miraculously)
- >75 homes damaged or destroyed
- 1.2M m^3 of material removed from debris basins

The Approach: Start with a relatively simple rainfall intensity-duration threshold-based system, incorporate additional understanding and tools as they become available

Talk Outline:

- Post-fire debris-flow processes
- Warning system operation and products
- Rainfall intensity-duration thresholds
  - Event-magnitude based thresholds
- Physical processes monitoring
- Hazard mapping

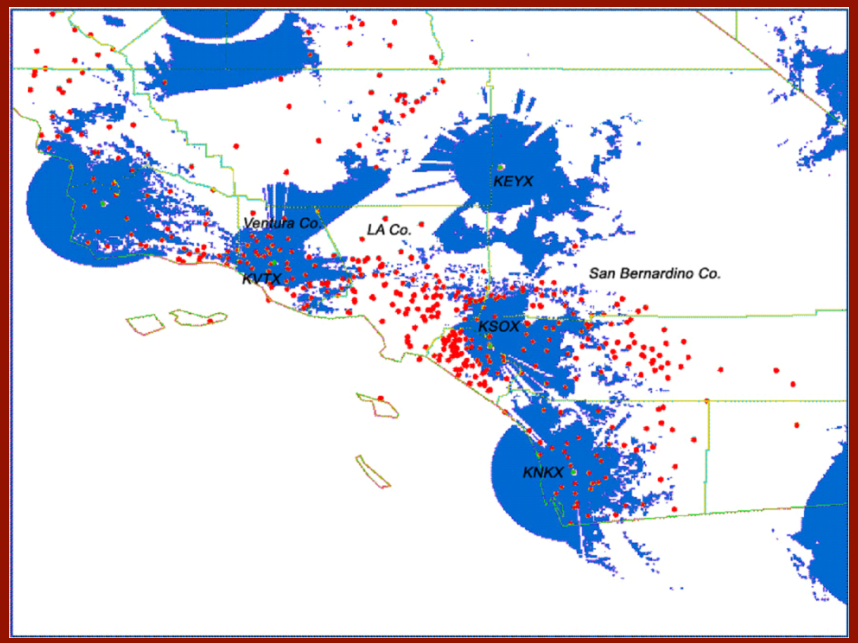
Lessons Learned sprinkled throughout

Post-fire Debris-Flow Processes

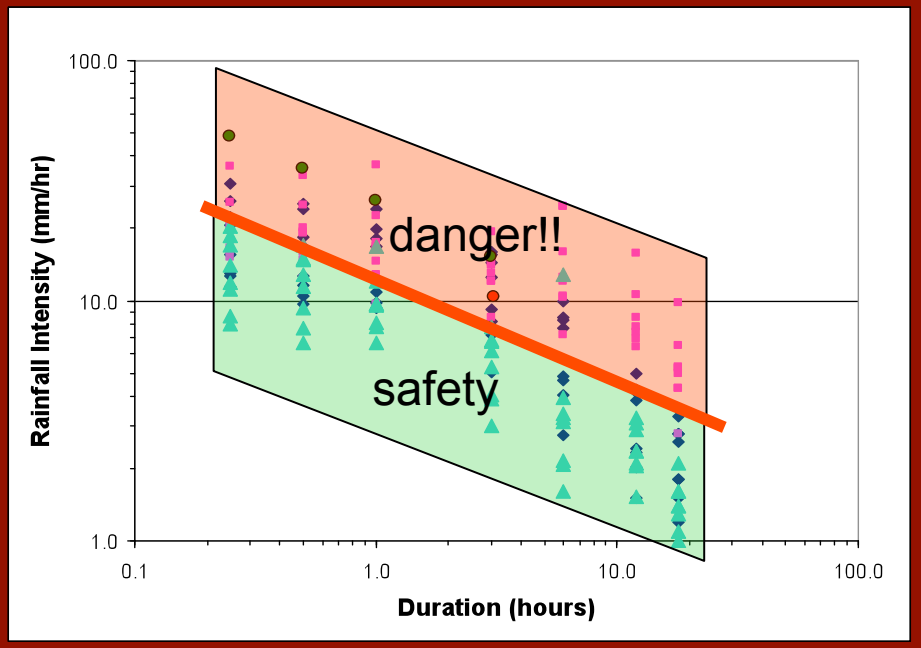
- No distinct, identifiable (landslide) source
- Great majority of material eroded from channel network
- Can occur in response to high-frequency (<5-yr-recurrence) storms, and first storm of the season

Debris flow generated through runoff-dominated erosion of material from hillslopes and channels

Warning System Operation:
Link NOAA/NWS precipitation forecasting and 24x7 operational capabilities
USGS Post-fire Debris Flow Research Project



Southern California radar coverage at 1 km (blue regions), and real-time rain gage locations (red dots).



First Cut: Rainfall threshold conditions for flash floods and debris flows in Ventura County

Warning System Operation and Products:

- Up to 7 days prior to potential weather event

  Mentioned in Area Forecast Discussion and Hazardous Weather Outlook

- 12 hrs to as much as 72 hrs ahead of event…

  Special Weather Statements and Hydrologic Outlooks are issued that outline possible storm conditions and mention the possibility of debris flows from recently burned areas

- 6 to 12 hrs before possible weather event…

  Flash Flood Watch issued for specific burned areas

  Local emergency-response, flood-control/public works, and highway officials and agencies are called

Warning System Operation and Products, con't:

- When the weather event is imminent, or occurring

  <u>Advisory</u> for debris flows is issued for specific recently-burned areas when rainfall rates are approaching or just below thresholds

  <u>Warning</u> for debris flows is issued for specific recently-burned areas when thresholds are exceeded

Watches vs Advisories vs Warnings ??

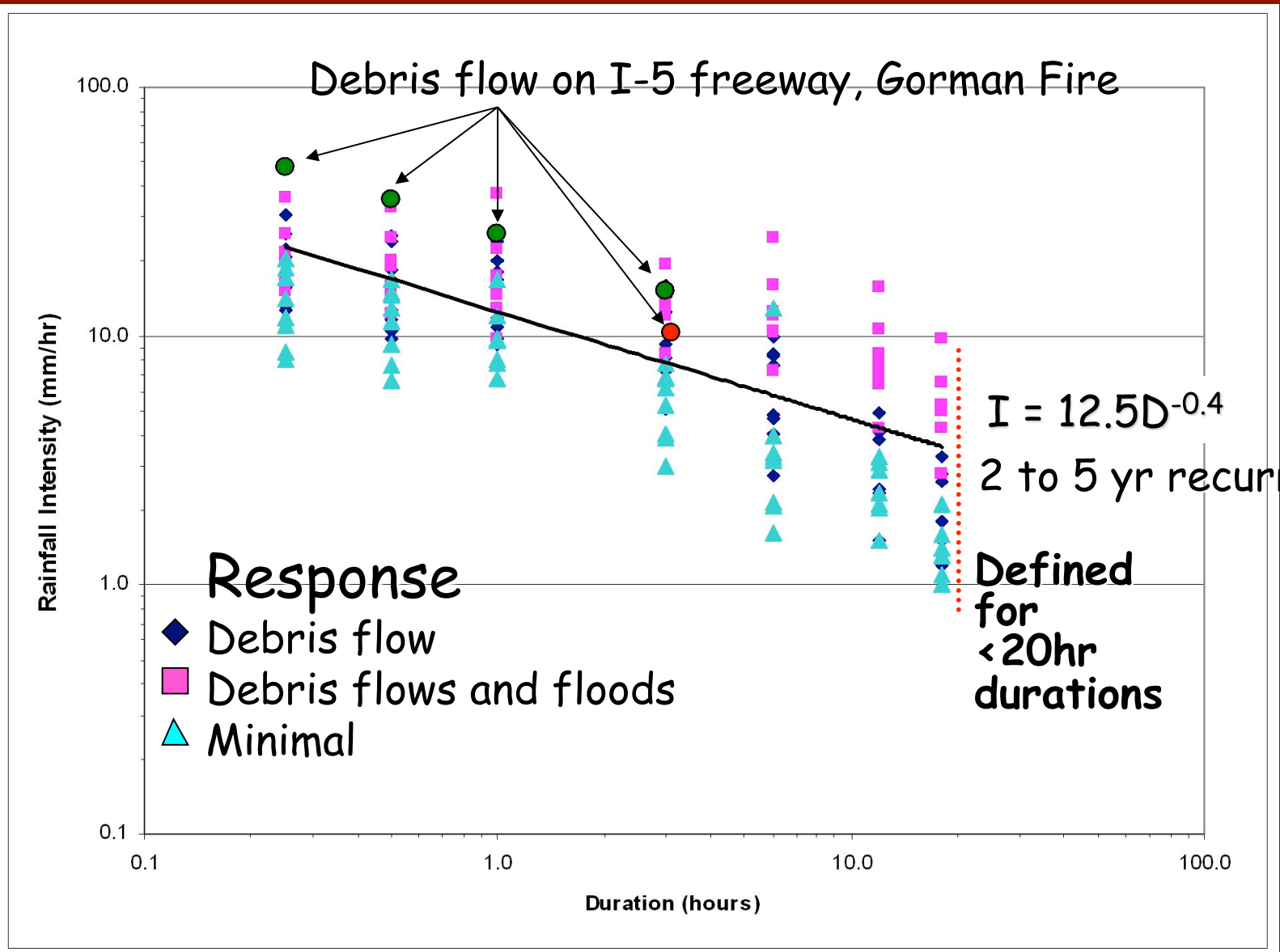
- Watch:
  6 to 12 hr lead times
  Increasing certainty that an event will occur

Most Valuable Product

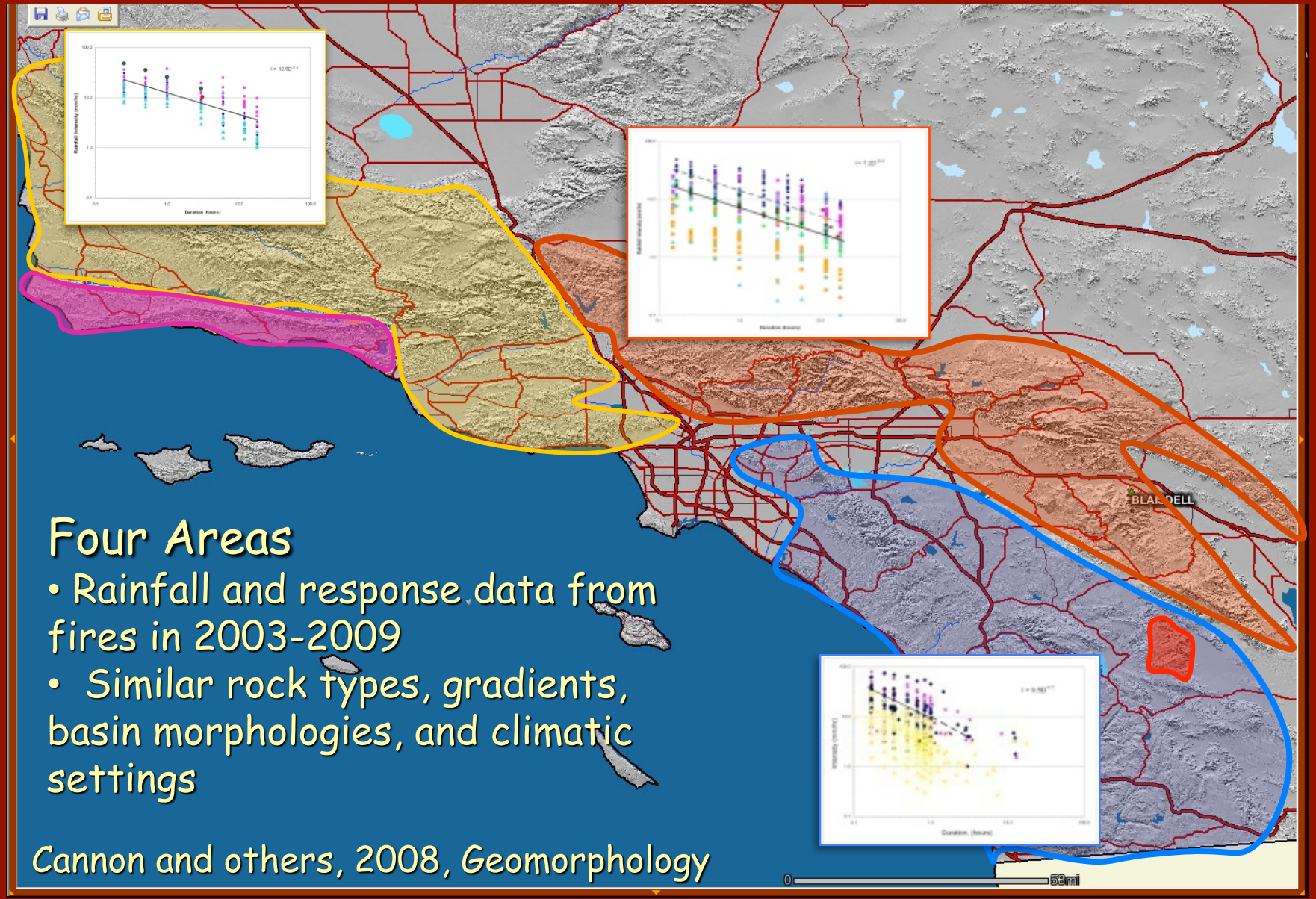
- Advisory:
  0 to 1 hr lead times
  Non-threatening event either imminent or is occurring

- Warning:
  0 to 1 hour lead times
  Life-threatening and/or property-damaging event is either imminent or occurring

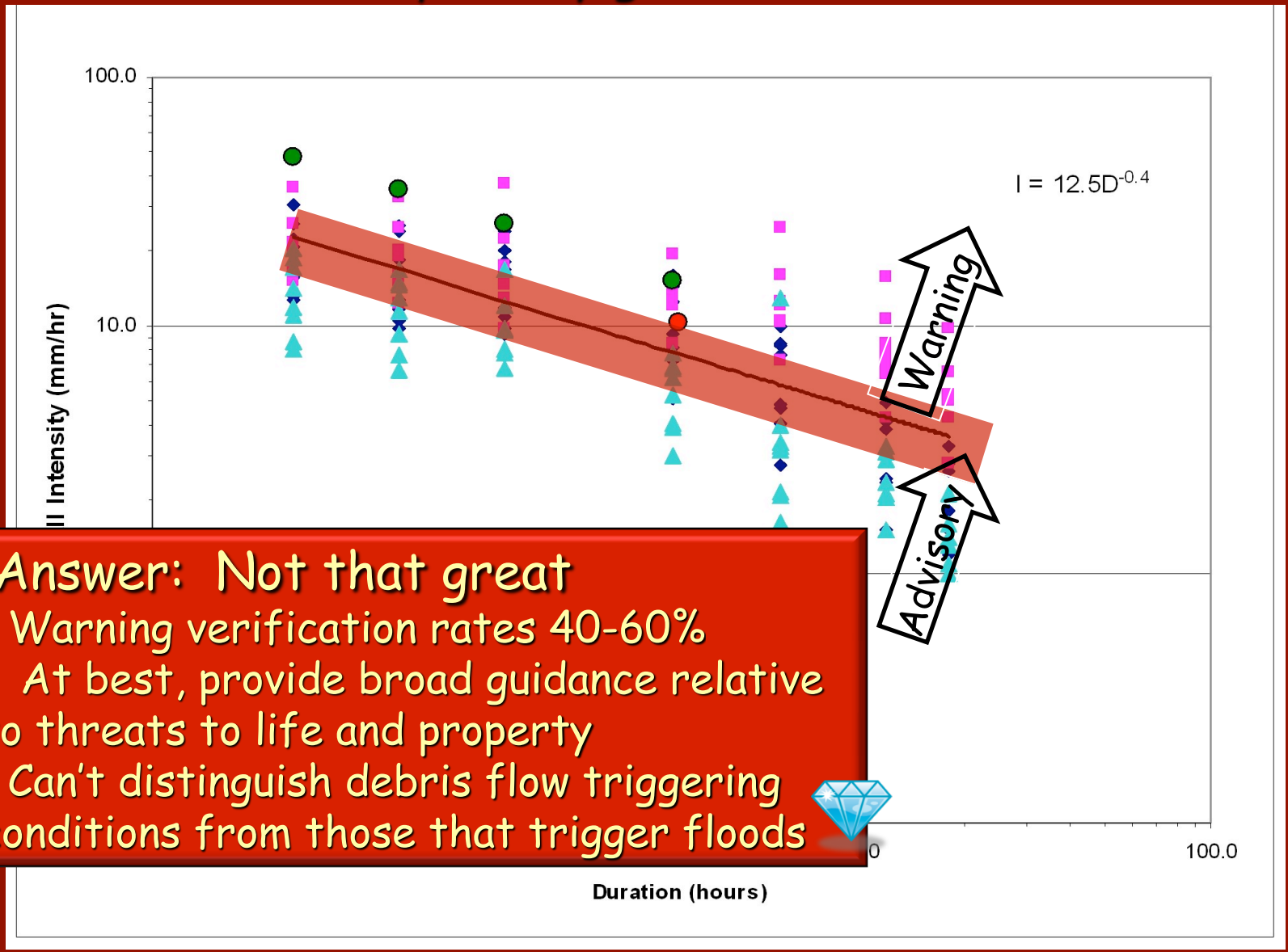
Rainfall intensity-duration threshold for So Cal



Rainfall Intensity-Duration Thresholds for Southern California Burned Areas



Question: How well did the warning system do when the thresholds were the primary guidance ?

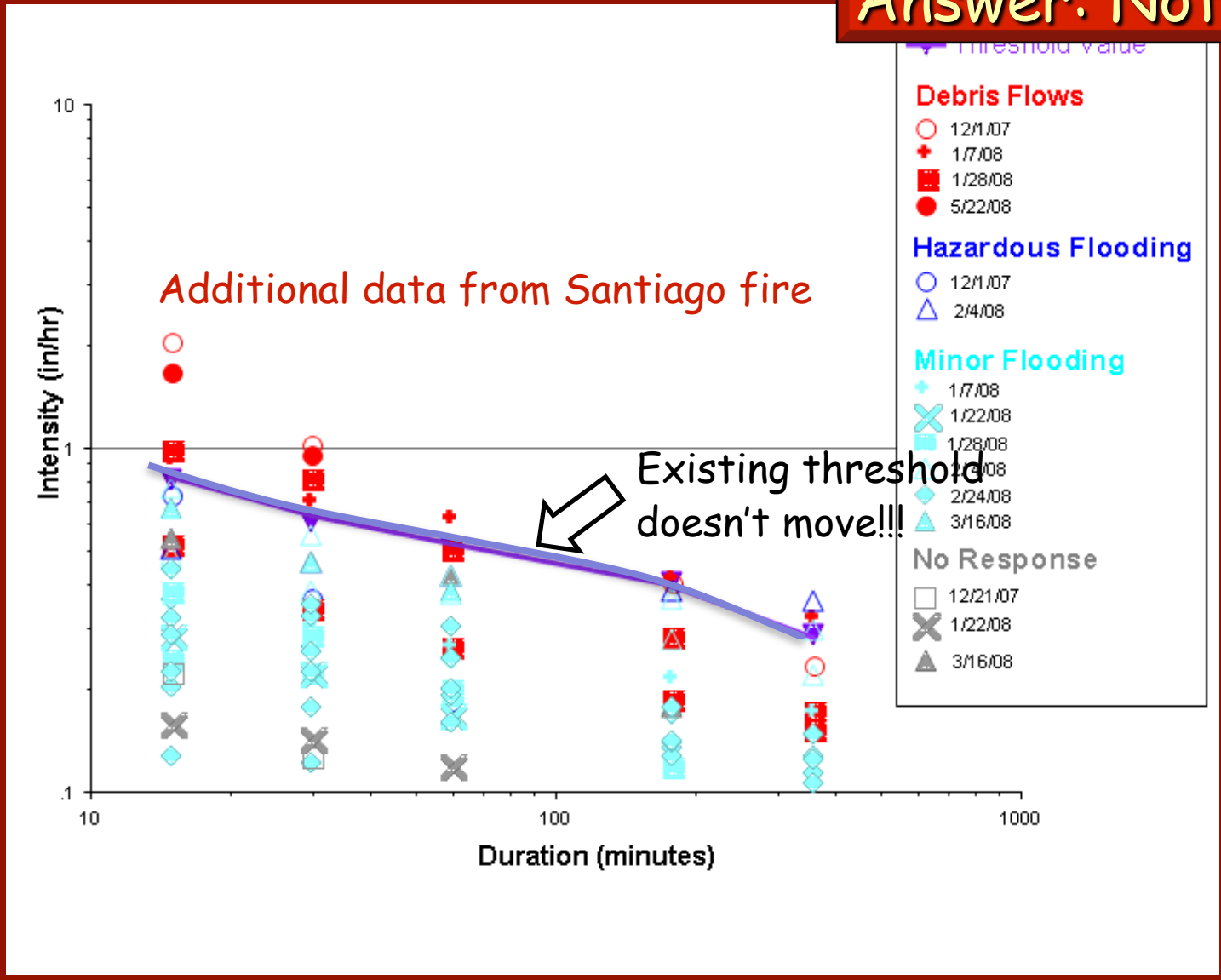


Answer: Not that great

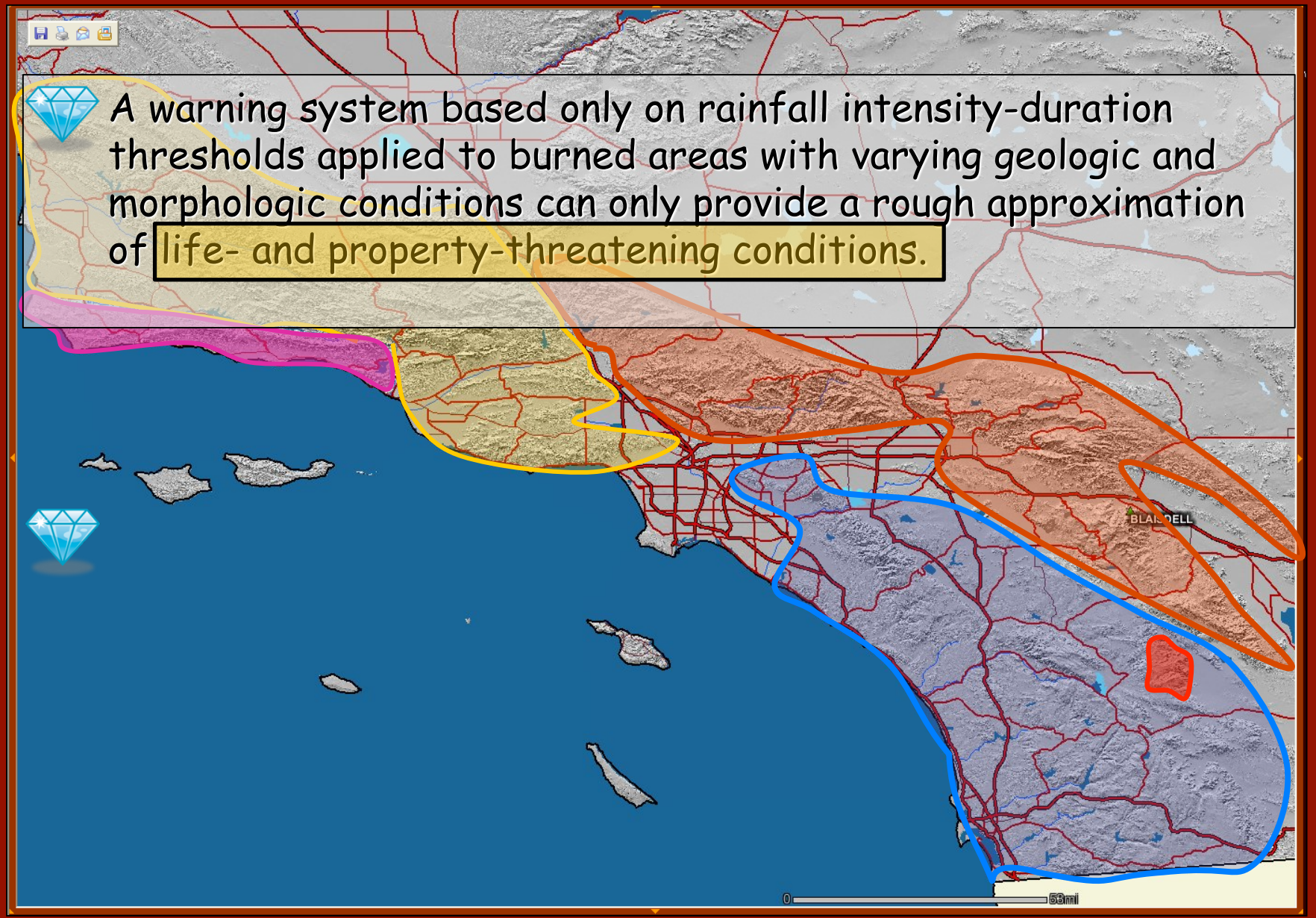
- Warning verification rates 40-60%
- At best, provide broad guidance relative to threats to life and property
- Can't distinguish debris flow triggering conditions from those that trigger floods

Question: Can additional data increase the precision or accuracy of existing thresholds?

Answer: Not so much



Rainfall Intensity-Duration Thresholds



Perceptions of Life- and Property-Threats are subjective

and vis a versa

Need quantitative representation of relative threats,
and measures of rainfall that trigger them

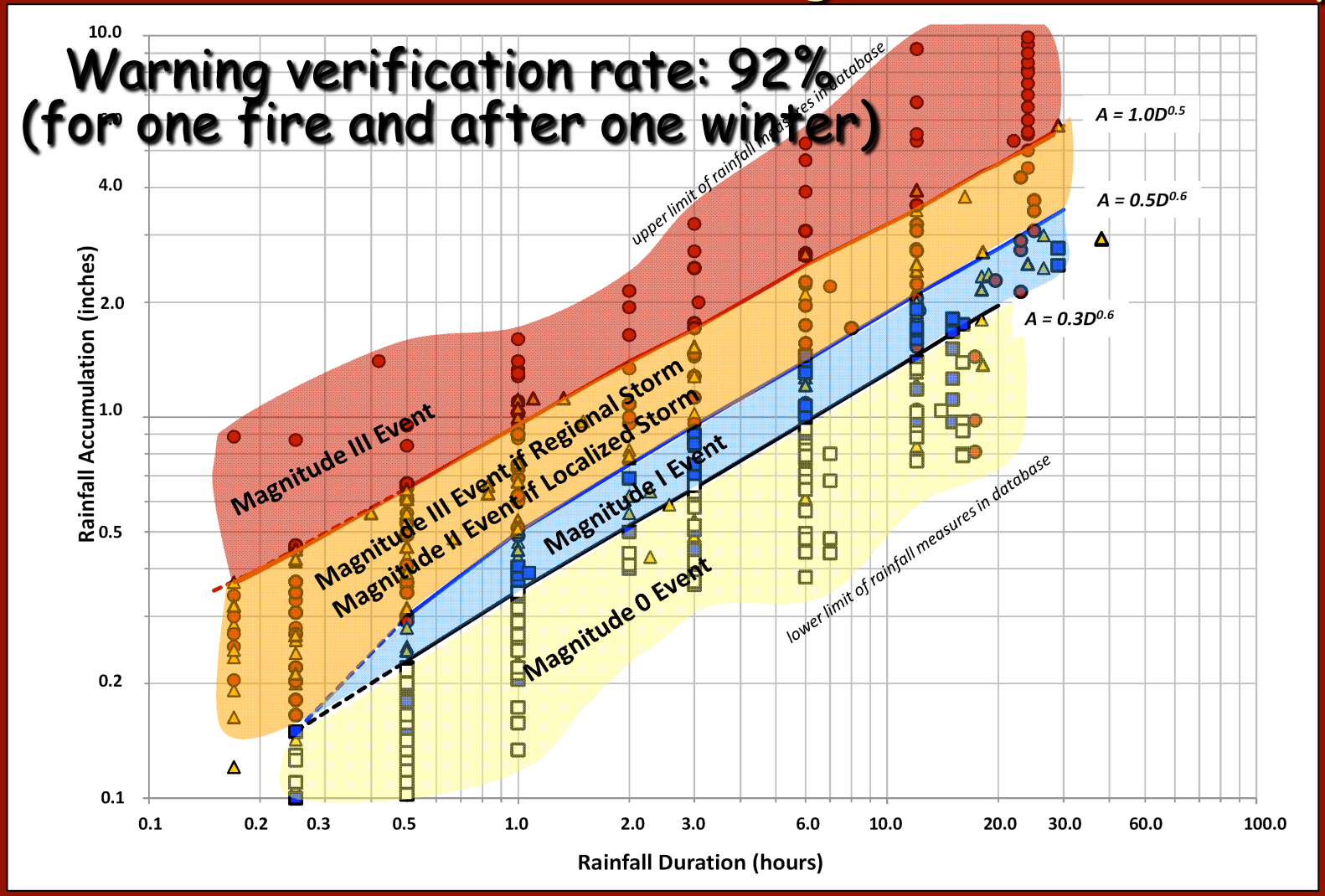
One person's threat can be another's no big deal

Rainfall thresholds for different magnitude events – Step 1:

Table 2. Magnitude classification for debris-flow and flood events. Modified from Jakob (2005) and Los Angeles Department of Public Works Event Level definitions (Los Angeles Department of Public Works, written communication, 2009).

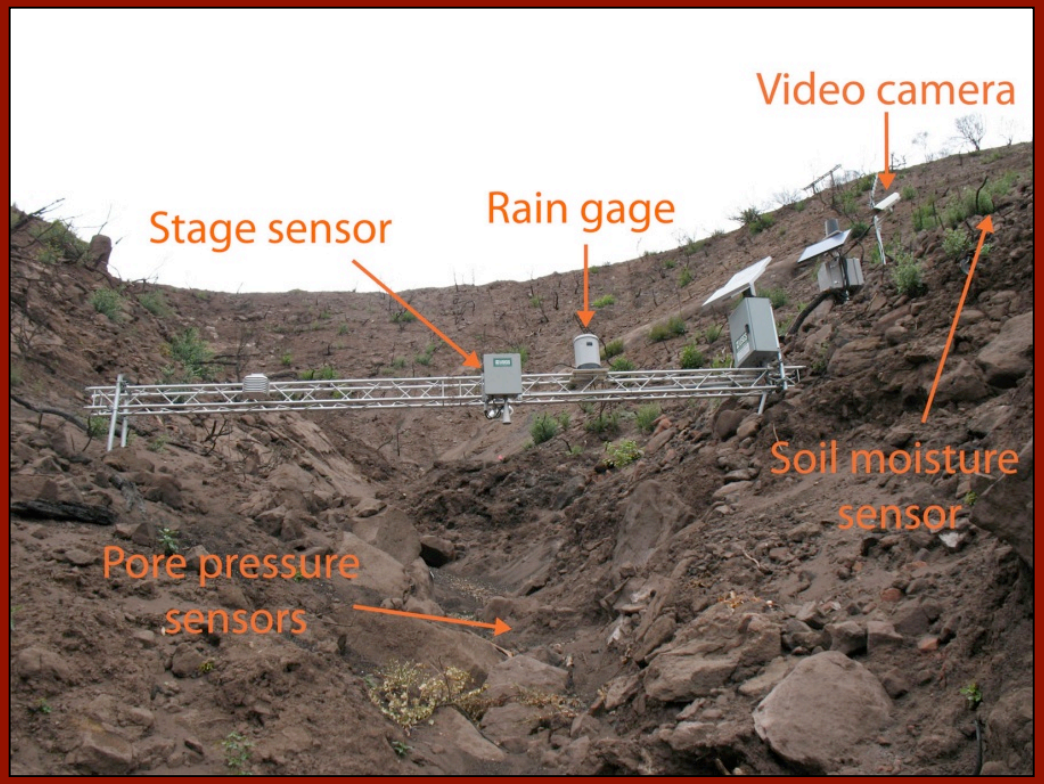
Event Classification	Criteria and potential consequences
Magnitude 0	• Negligible response
Magnitude I	• Small (<1,000 cubic yards) debris flows or flooding produced from one or two drainages basins or in one or two locations. • Some culverts and storm drains may be blocked, streets may be partially flooded or blocked by debris, and cars may be partially buried. • Houses may be damaged and small wooden buildings may be destroyed. Few, if any, larger buildings will be threatened.
Magnitude II	• Two to five moderately-sized (1,000 to 10,000 cubic yards) debris flows or one large (>10,000 cubic yards) event produced from two to five drainage basins which impact the built environment. • Several culverts and storm drains may be blocked, several streets and roads may be flooded or completely blocked by debris, and several cars may be buried. • Several homes, buildings, streets, and bridges may be damaged.
Magnitude III	• Widespread and abundant debris flows and flooding with volumes in excess of 10,000 cubic yards produced from more than five drainage basins resulting in a significant impact to the built environment. • Many culverts, storm drains, and streets may be completely blocked by debris, making many streets unsafe for travel. • Several large buildings (including homes), sections of infrastructure corridors, and bridges may be destroyed.

Rainfall thresholds for different magnitude events – Step 2:



When this information is available, better approximations of life- and property-threatening conditions are possible.

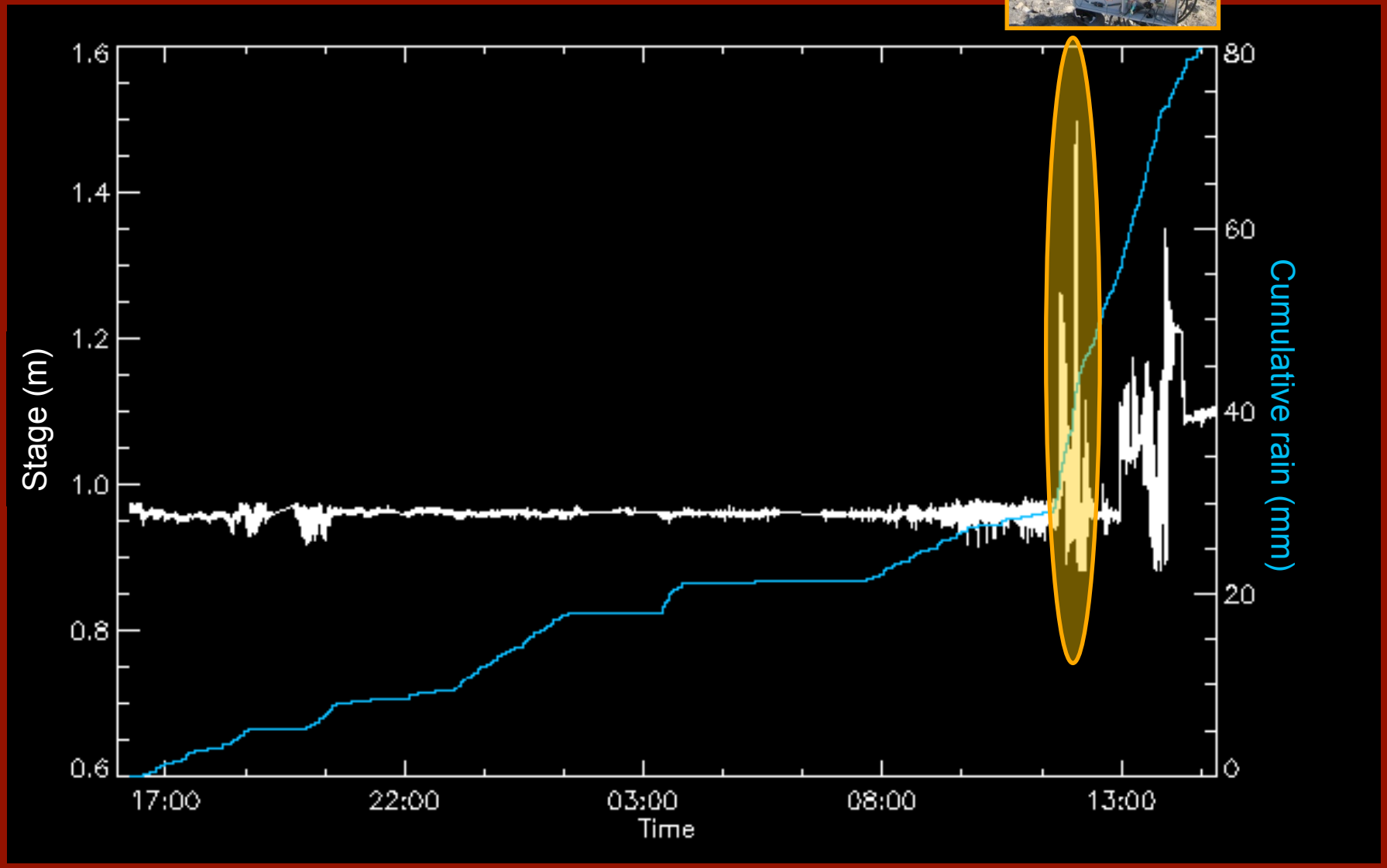
Physical Process Monitoring



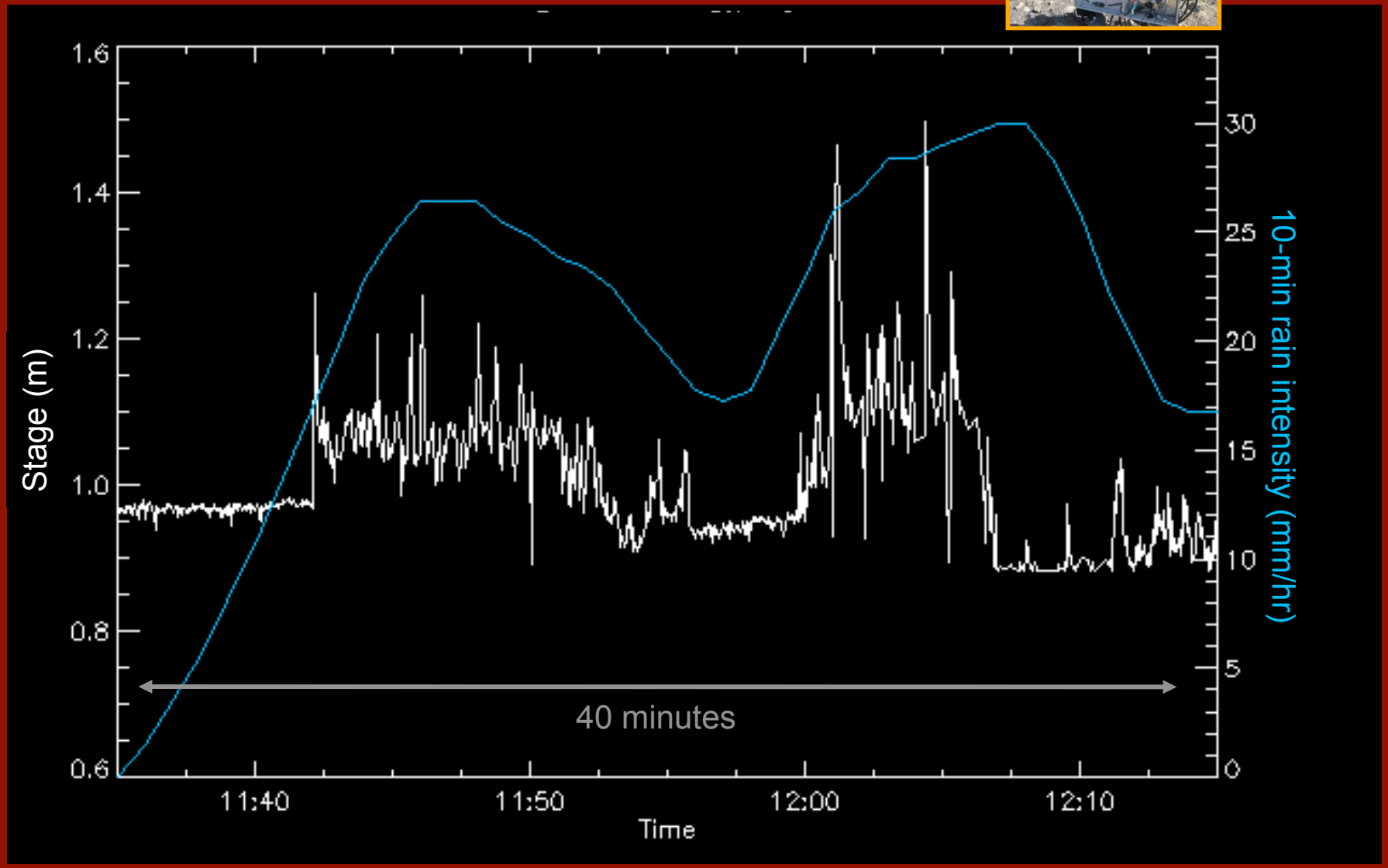
Direct measurements provide vital data on:

- Timing of overland flow and debris flow
- Overland flow and debris-flow magnitudes
- Hydrologic conditions leading up to events

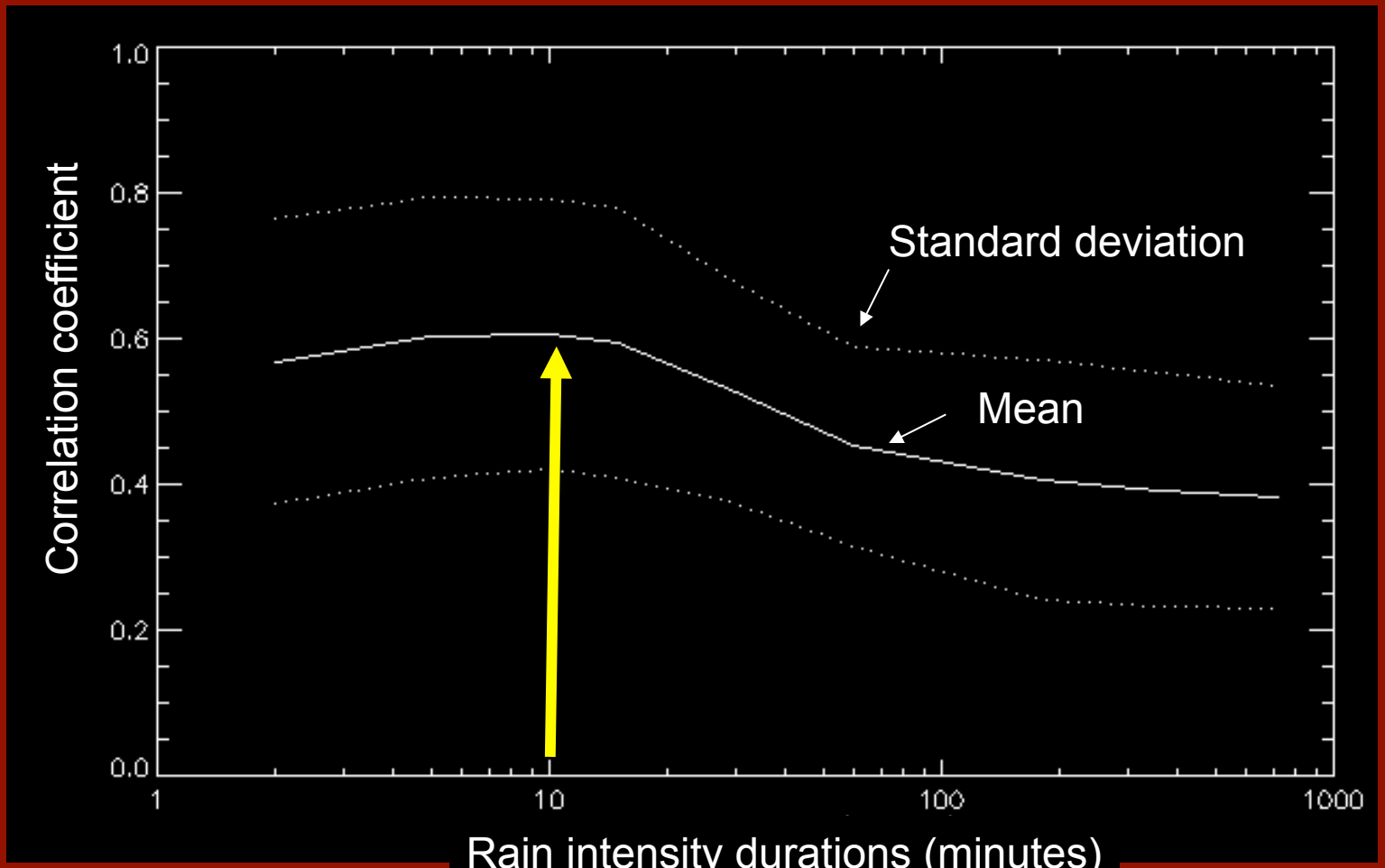
Dunsmore 2


1.6
1.4
1.2
1.0
0.8
0.6
Stage (m)
80
60
40
20
0
Cumulative rain (mm)
17:00
22:00
03:00
08:00
13:00
Time

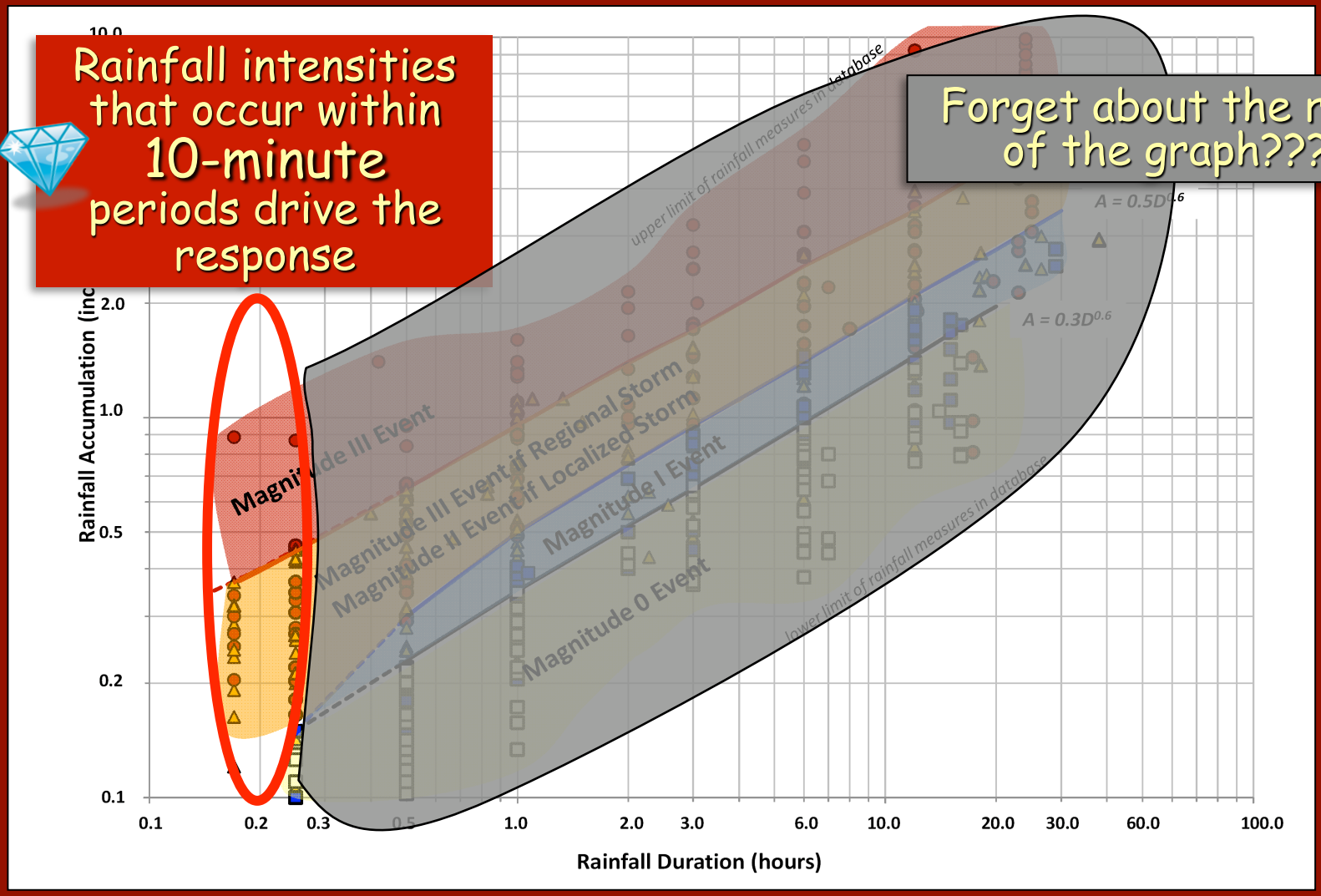
Dunsmore 2


Stage (m)
1.6
1.4
1.2
1.0
0.8
0.6
10-min rain intensity (mm/hr)
30
25
20
15
10
5
0
40 minutes
11:40
11:50
12:00
12:10
Time

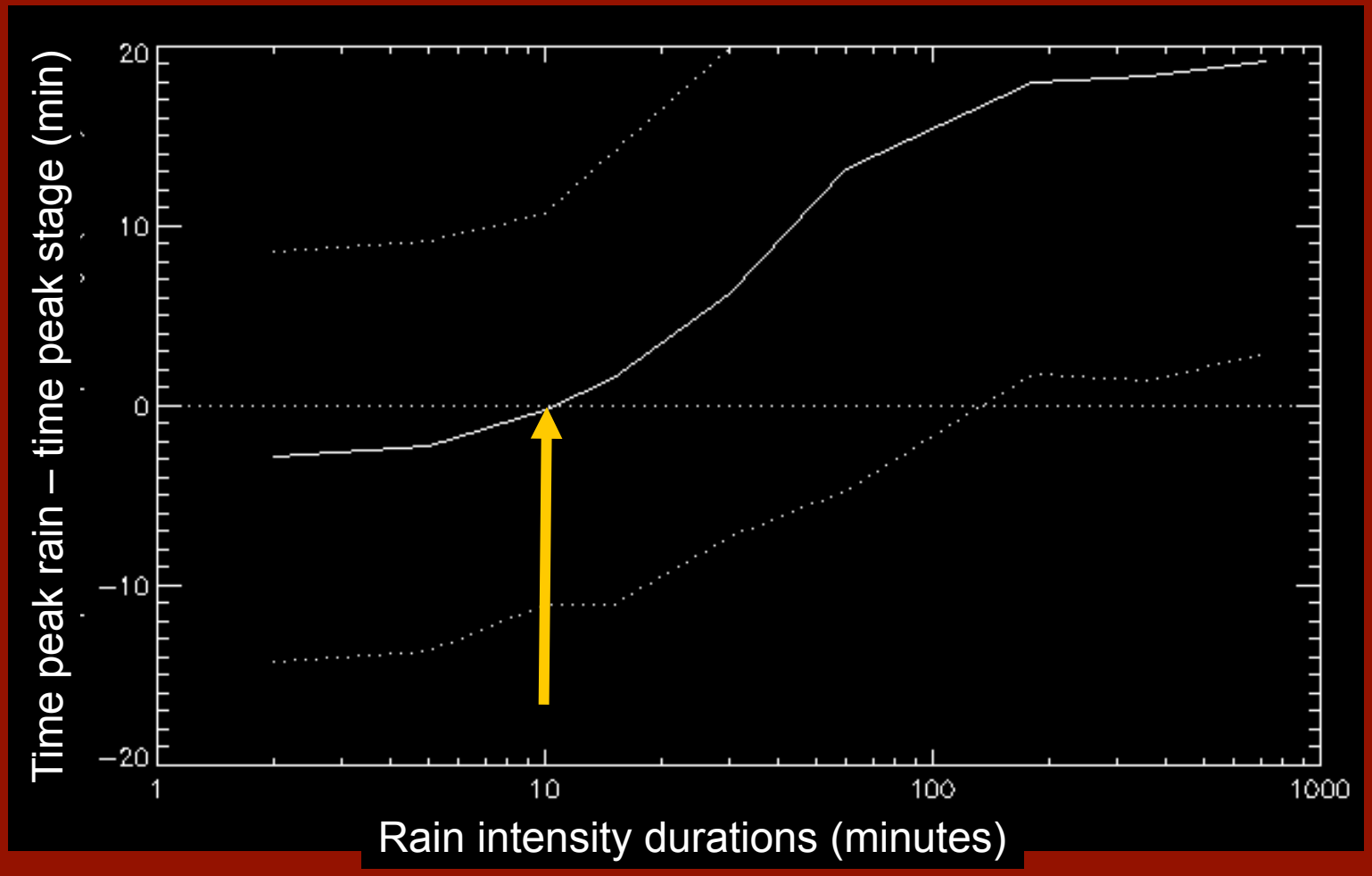
Stage-Rainfall Intensity correlation (27 events)



Sort of good news: Of all durations examined, 10-minute peak intensity most strongly correlated stage

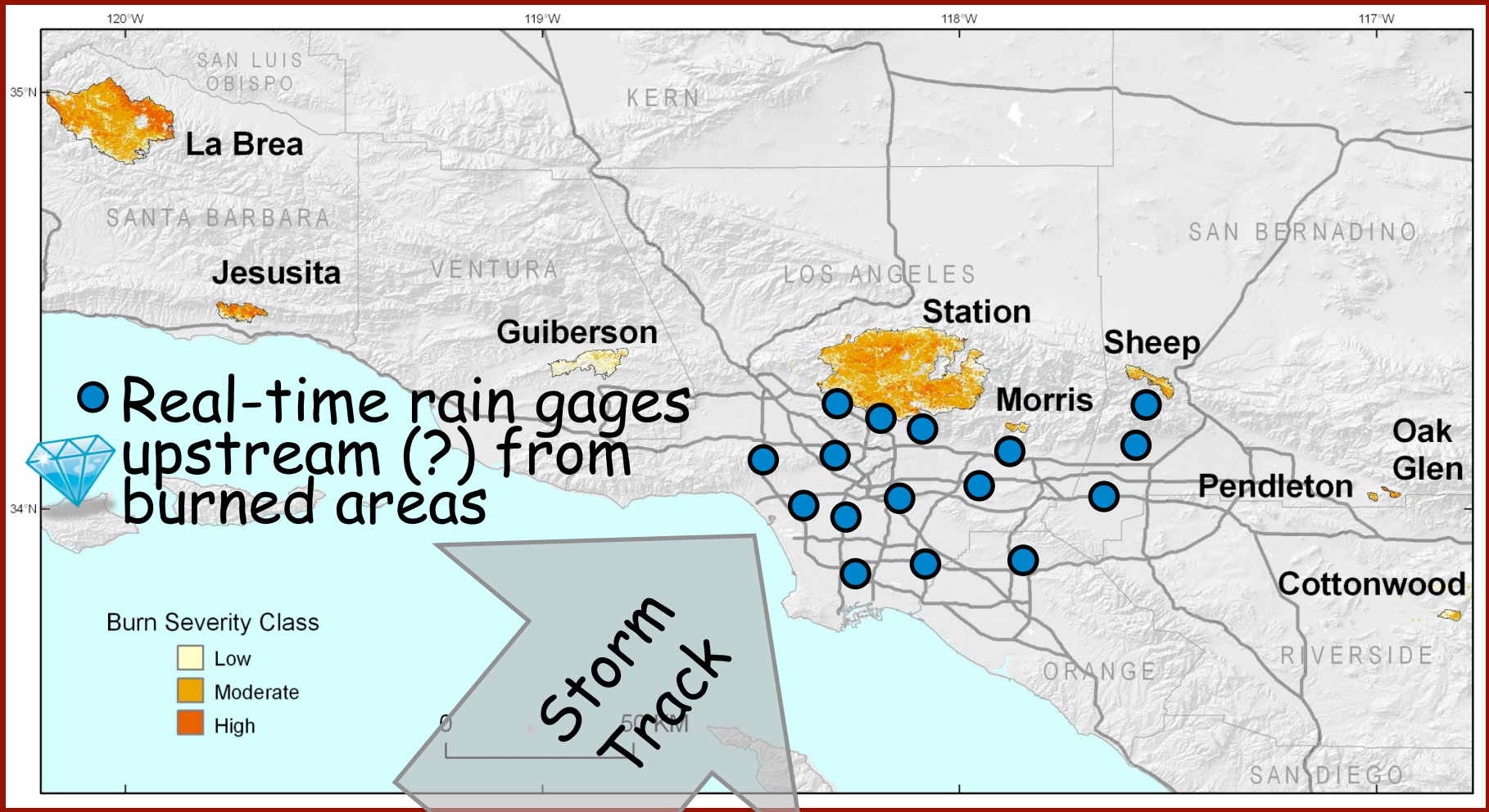

Rainfall intensities that occur within 10-minute periods drive the response
Forget about the rest of the graph???
Rainfall Accumulation (inc
Rainfall Duration (hours)
0.1
0.2
0.3
0.5
1.0
2.0
3.0
6.0
10.0
20.0
30.0
60.0
100.0
0.1
0.2
0.5
1.0
2.0
upper limit of rainfall measures in database
lower limit of rainfall measures in database
A = 0.5D^0.6
A = 0.3D^0.6
Magnitude III Event if Regional Storm
Magnitude II Event if Localized Storm
Magnitude I Event
Magnitude 0 Event

Time lag between rainfall and stage (all 27 events)

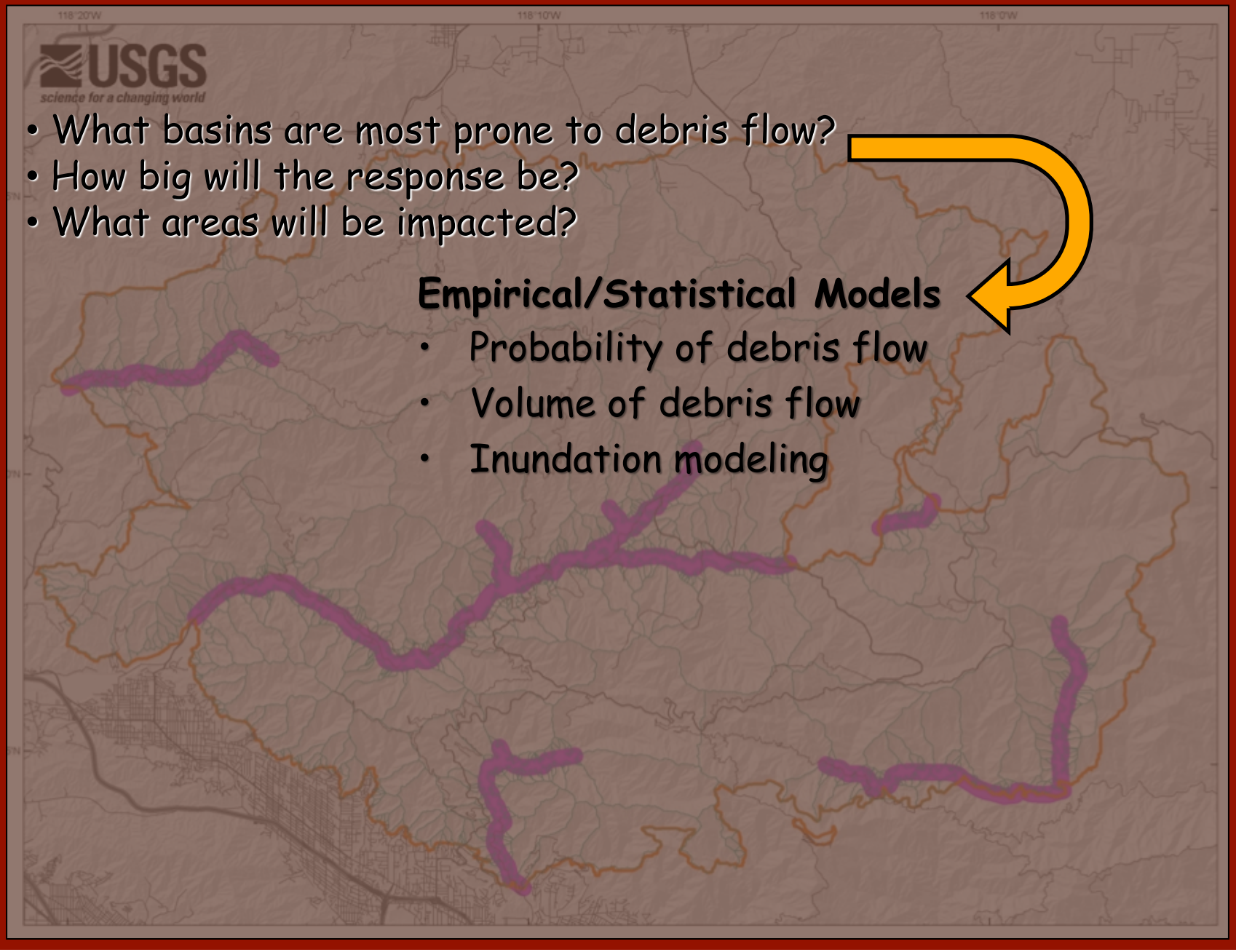


Not so good news: Lag time between 10-minute peak intensity and stage = 0 minutes

How do you warn for this fast of a response ????



Post-Fire Debris-Flow Hazards Mapping

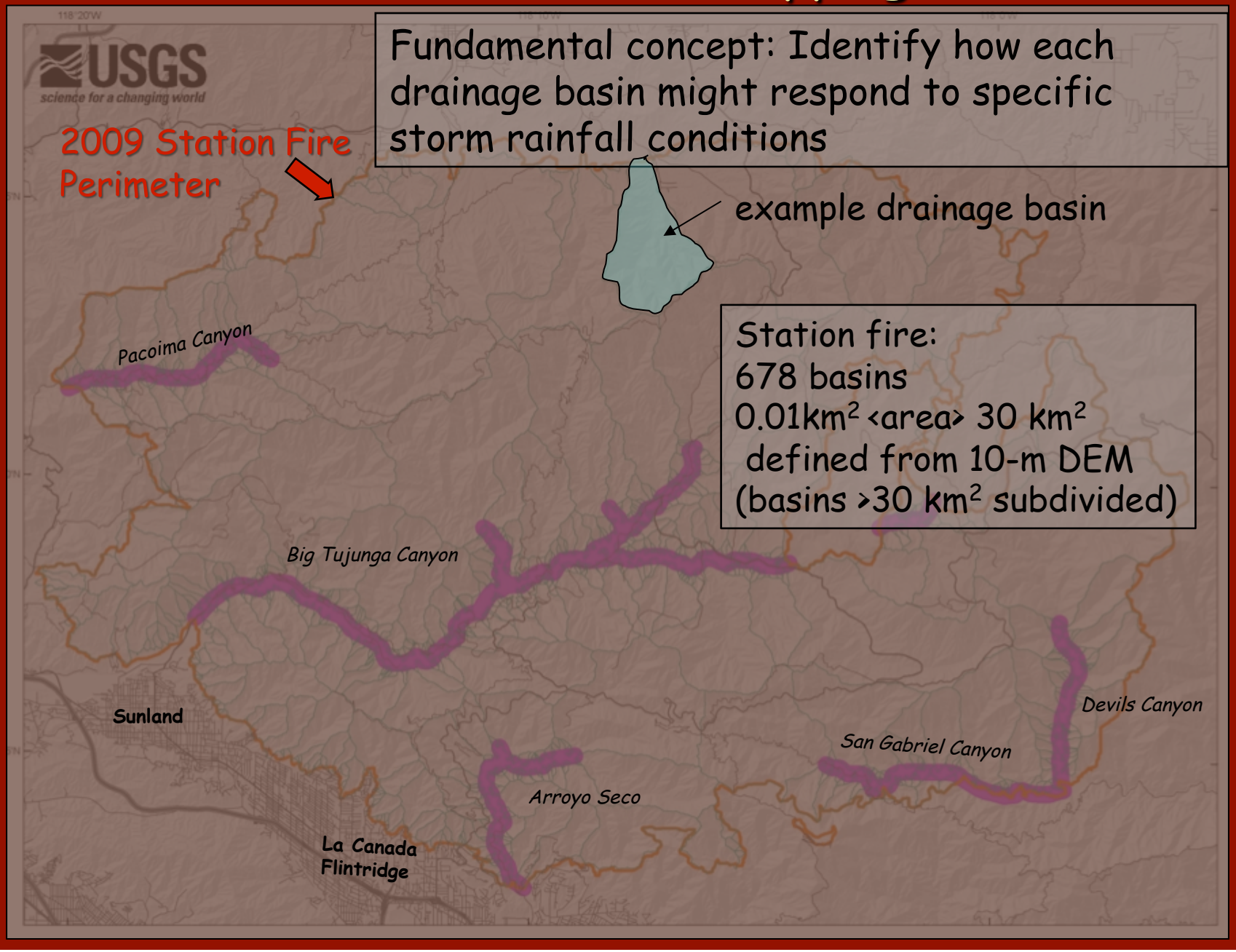


- What basins are most prone to debris flow?
- How big will the response be?
- What areas will be impacted?

Empirical/Statistical Models

- Probability of debris flow
- Volume of debris flow
- Inundation modeling

Post-fire debris-flow hazard mapping



Variables used to characterize debris-flow probability and volume for each basin

	Probability Model (n=517, 2003-2009)	Volume Model (n=40) (single storm/volume)
Burned extent:	Percent of basin burned at high and moderate severity	Total area burned
Soil properties:	Percent clay	None
	K-factor (erodibility)	
Basin gradients:	Length of the longest flow path	Length of the longest flow path
	Elevation change	Elevation change
	Percent of burned basin with slopes greater than or equal to 30%	
Storm rainfall:	Average storm intensity	Total storm rainfall
	Storm duration	

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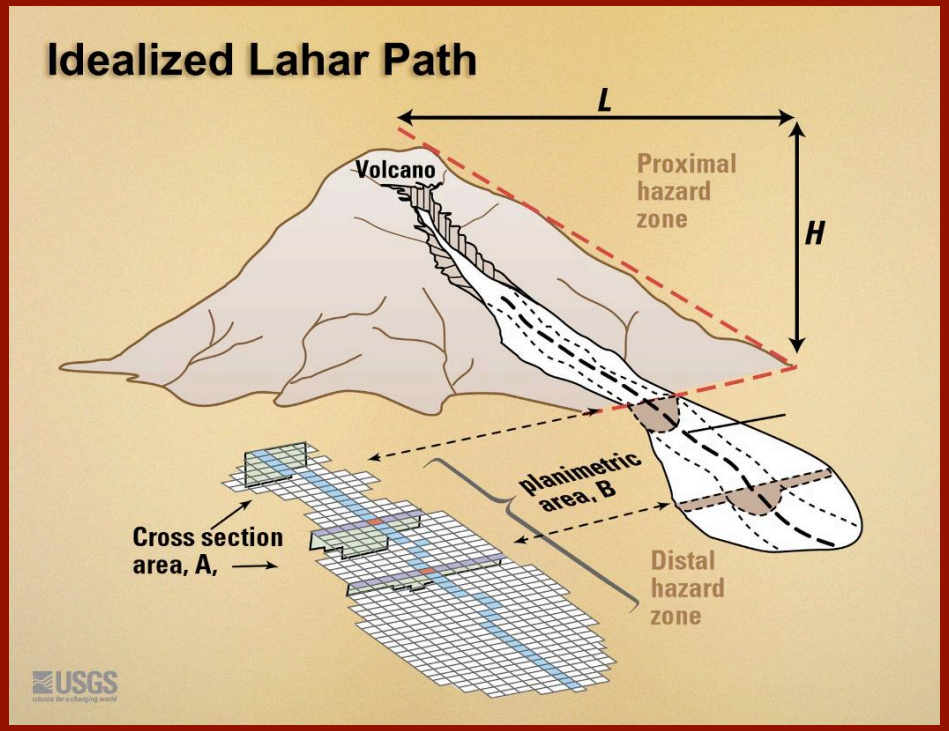
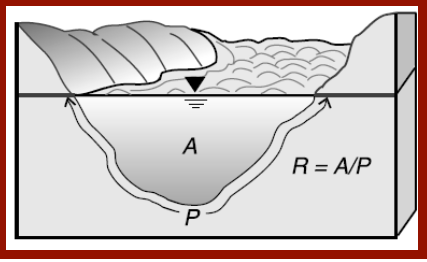
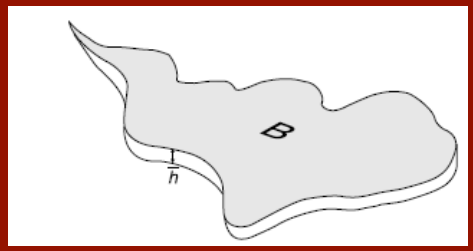
Debris-flow inundation mapping







$= f(V)$

Adapted for Post-Fire Debris Flows:

$A = 0.3 * V^{0.67}$

$B = 28 * V^{0.67}$

Approach based on LAHARZ, Iverson and Schilling

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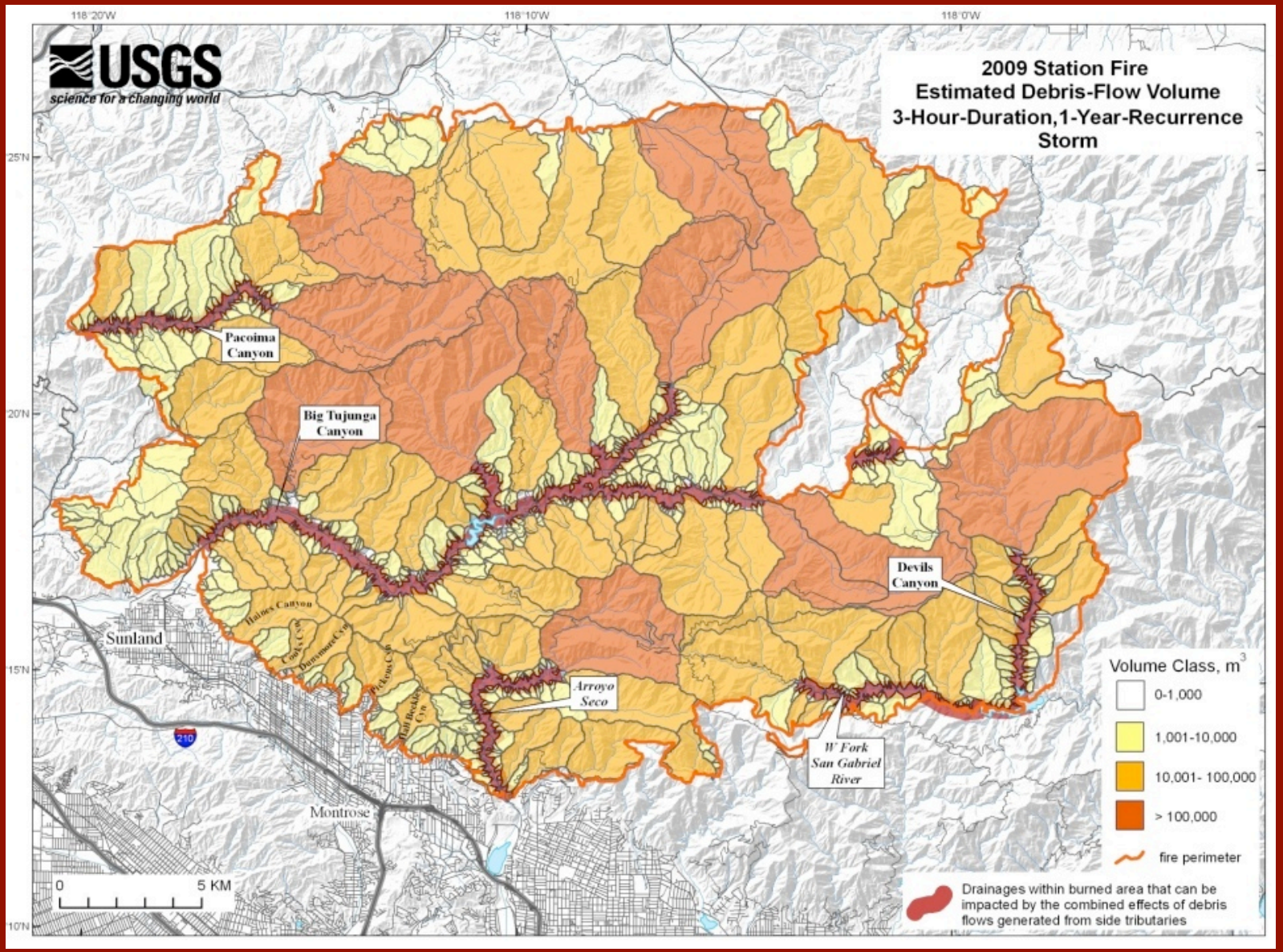
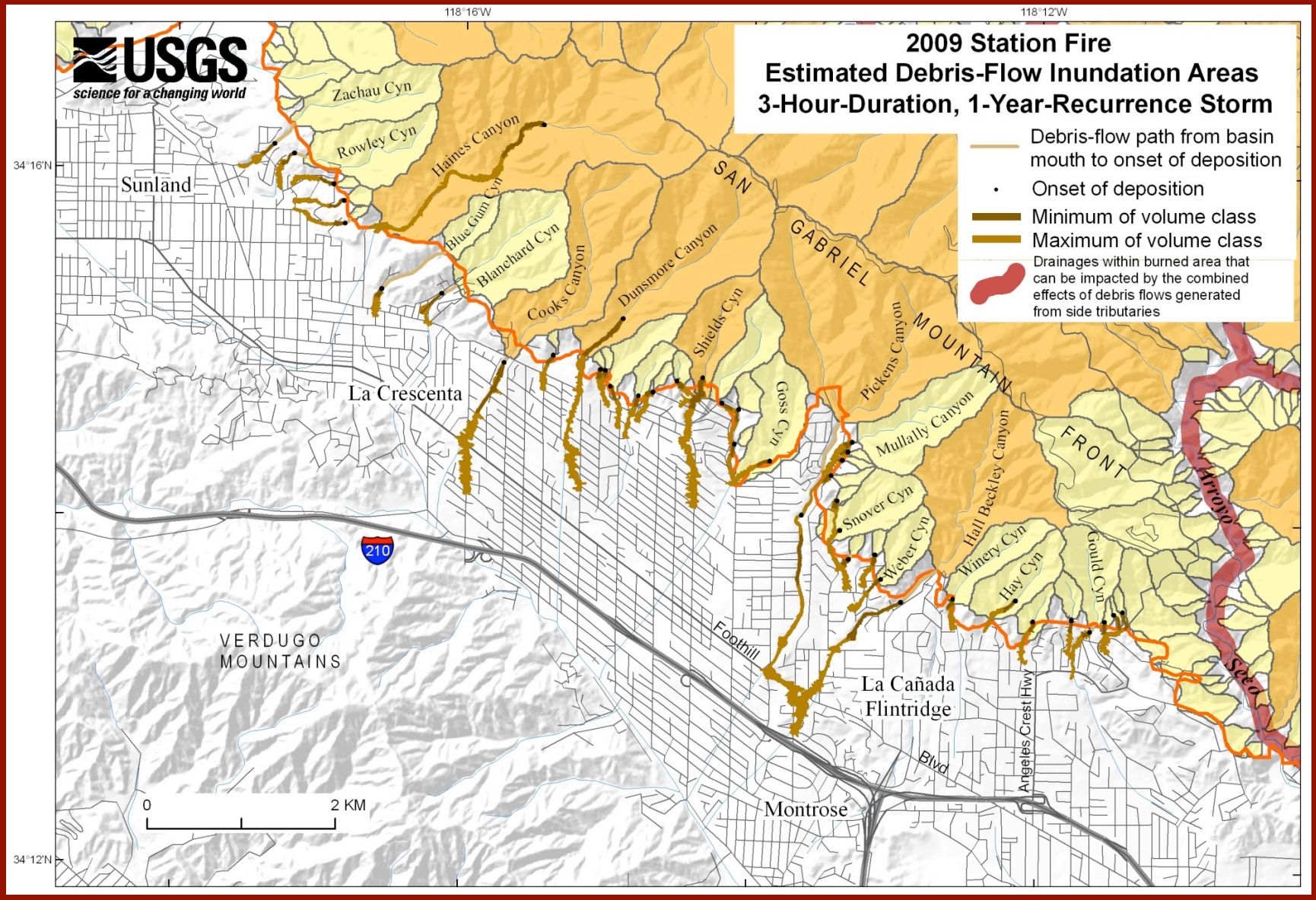
Map of potential debris-flow volumes in response to a 3-hr-duration, 1-yr-recurrence thunderstorm



Map of Potential Debris-Flow Inundation Areas
3-hr-duration, 1-yr-recurrence storm
All debris basins full, experience blocked spillways, channels or drains



Debris-Flow Hazard Maps on NWS Interactive Web Site:
Provide spatially explicit information about hazards

Summary of Lessons Learned from 5 years of Warning System Operation:

1.WATCHES are a more useful product than WARNINGS because their longer lead times allow for effective planning and response
2.Personal contact with appropriate agencies is appreciated and can be necessary for effective response to information provided
3. Warning systems that rely on rainfall intensity-duration information alone will result in high false alarm rates.

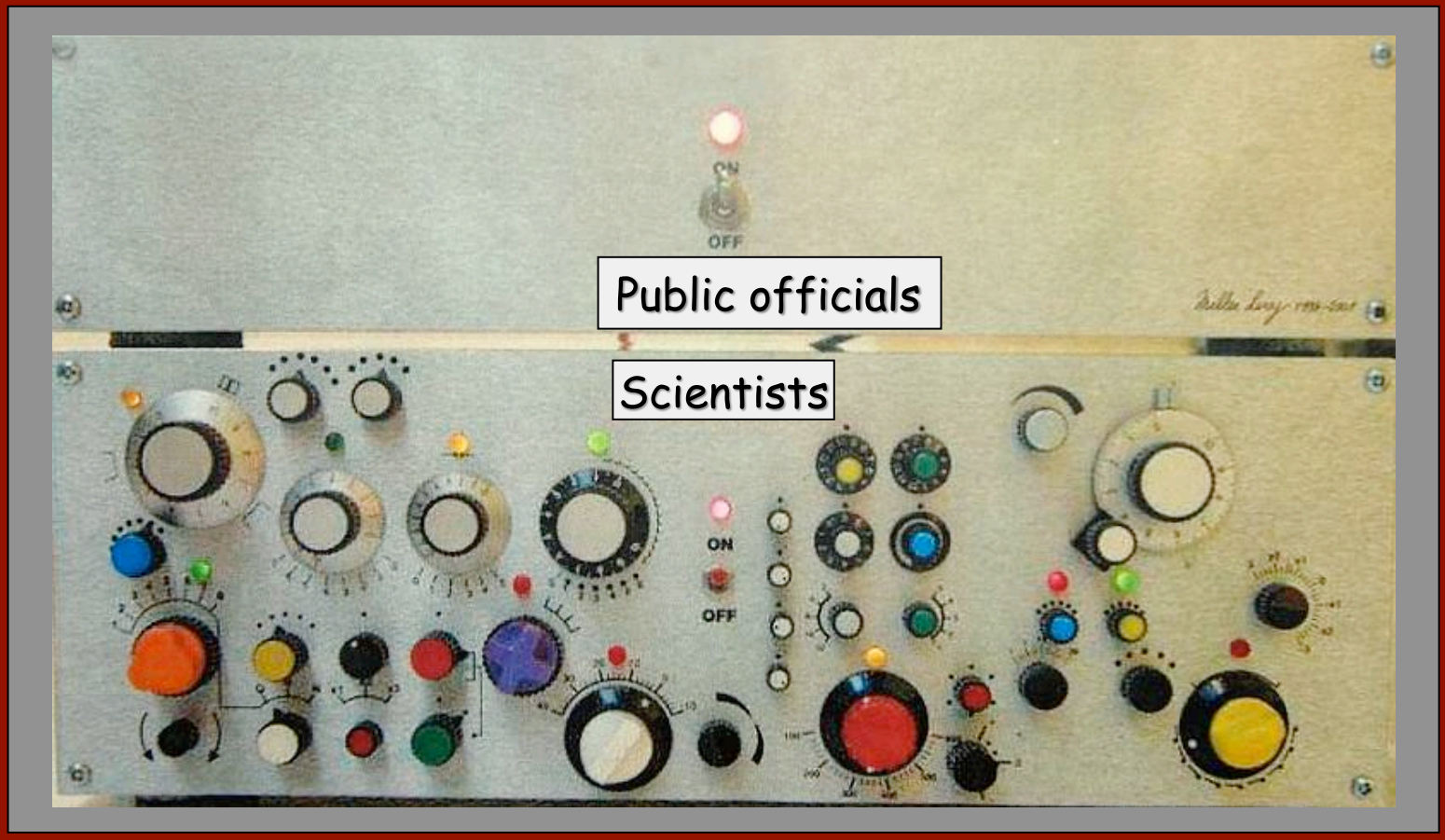
Summary of Lessons Learned from 5 years of Warning System Operation:

4. When information on response magnitude can be linked with rainfall information, better approximations of life- and property-threatening conditions are possible.

5. Debris-flow response to rainfall is so rapid that hillslope and channel monitoring cannot provide practical warning. Warning must come from weather forecasts and upstream precipitation measurements

6. Hazard mapping is necessary to provide spatially explicit information about specific impacts

The challenge is for scientists to articulate uncertainty without losing credibility and to give public officials the information they need for decision-making



this requires to bridge the gap between scientific output (probability) and the boolean logic (YES-NO) of decision-makers

Thank you for your attention. Questions???